Ch 15  Manual Assembly Lines

Sections:
1. Fundamentals of Manual Assembly Lines
2. Analysis of Single Model Assembly Lines
3. Line Balancing Algorithms
4. Mixed Model Assembly Lines
5. Workstation Considerations
6. Other Considerations in Assembly Line Design
7. Alternative Assembly Systems
Manual Assembly Lines

- Factors favoring the use of *manual assembly lines*:
  - High or medium demand for product
  - Identical or similar products
  - Total work content can be divided into work elements
  - It is technologically impossible or economically infeasible to automate the assembly operations
- Most consumer products are assembled on manual assembly lines
Why Assembly Lines are so Productive

- **Specialization of labor** (division of labor)
  - Learning curve (a large job is divided into small tasks and each worker becomes a specialist in performing the single task)

- **Interchangeable parts**
  - Components made to close tolerances

- **Work flow principle**
  - Products are brought to the workers (traveling the minimum distance between stations)

- **Line pacing**
  - Workers must complete their tasks within the cycle time of the line (which paces the line to maintain a specified production rate)
## Typical Products Made on Assembly Lines

<table>
<thead>
<tr>
<th>Products</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobiles</td>
<td>Personal computers</td>
</tr>
<tr>
<td>Cooking ranges</td>
<td>Power tools</td>
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<tr>
<td>Dishwashers</td>
<td>Refrigerators</td>
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<tr>
<td>Dryers</td>
<td>Telephones</td>
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<tr>
<td>Furniture</td>
<td>Toasters</td>
</tr>
<tr>
<td>Lamps</td>
<td>Trucks</td>
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<tr>
<td>Luggage</td>
<td>Video DVD players</td>
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<tr>
<td>Microwave ovens</td>
<td>Washing machines</td>
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Manual Assembly Line Defined

“A production line consisting of a sequence of workstations where assembly tasks are performed by human workers as the product moves along the line”

- Organized to produce a single product or a limited range of products
  - Each product consists of multiple components joined together by various assembly work elements
    - Total work content - the sum of all work elements required to assemble one product unit on the line
Configuration of a manual assembly line with $n$ manually operated workstations
Manual Assembly Line

- Products are assembled as they move along the line
  - At each station a portion of the total work content (assigned tasks) is performed on each unit
- Base parts are launched onto the beginning of the line at regular intervals (cycle time)
  - Workers add components to progressively build the product
Assembly Workstation

“A designated location along the work flow path at which one or more work elements (tasks) are performed by one or more workers”

Typical operations performed at manual assembly stations

<table>
<thead>
<tr>
<th>Adhesive application</th>
<th>Electrical connections</th>
<th>Snap fitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealant application</td>
<td>Component insertion</td>
<td>Soldering</td>
</tr>
<tr>
<td>Arc welding</td>
<td>Press fitting</td>
<td>Stitching/stapling</td>
</tr>
<tr>
<td>Spot welding</td>
<td>Riveting</td>
<td>Threaded fasteners</td>
</tr>
</tbody>
</table>
Work Transport Systems

- Two basic categories:
  - **Manual**
  - **Mechanized**

Both methods provide the fixed routing (all work units proceed through the same sequence of operations) that is characteristic of production lines.
Manual Work Transport Systems

“Work units are moved between stations by the workers without the aid of a powered conveyor”

- Types:
  - Work units moved in batches (transfer batch)
  - Work units moved one at a time

- Problems:
  - Starving of stations (waiting for a work unit)
  - Blocking of stations (cannot pass the work unit to the next station)
  - No pacing
Mechanized Work Transport Systems

“Work units are moved by powered conveyor or other mechanized apparatus”

- Categories:
  - Work units attached to conveyor (large and heavy product – worker walks along)
  - Work units are removable from conveyor (not a fixed cycle time)

- Problems
  - Starving of stations
  - Incomplete units (if the worker runs out of time)
Types of Mechanized Work Transport

- **Continuous transport** (see -13)
  - Conveyor moves at constant speed
- **Synchronous transport** (for automated lines) (see – 14)
  - Work units are moved simultaneously with stop-and-go (intermittent) motion to next stations
- **Asynchronous transport** (see -15)
  - Work units are moved independently between workstations
  - Queues of work units can form in front of each station
Continuous Transport

Conveyor moves at constant velocity $v_c$
Synchronous Transport

All work units are moved simultaneously to their respective next workstations with quick, discontinuous motion (intermittent transport).
Asynchronous Transport

Work units move independently, not simultaneously. A work unit departs a given station when the worker releases it. Small queues of parts can form at each station.
Material Handling Equipment for Mechanized Work Transport

Continuous transport
(Ch. 10)

Overhead trolley conveyor
Belt conveyor
Drag chain conveyor

Synchronous transport
(Ch. 16)

Walking beam
Rotary indexing machine

Asynchronous transport
(Ch. 10)

Power-and-free conveyor
Cart-on-track conveyor
Automated guided vehicles

Video 1    Video 2
Line Pacing

- A manual assembly line operates at a certain cycle time - On average, each worker must complete his/her assigned task within this cycle time or else the required production rate will not be achieved.
- Pacing provides a discipline for the assembly line workers that more or less guarantees a certain production rate for the line
- Several levels of pacing:
  1. Rigid pacing
  2. Pacing with margin
  3. No pacing
Rigid Pacing

- Each worker is allowed only a certain fixed time each cycle to complete the assigned task
  - Allowed time is set equal to the cycle time less repositioning time
  - Synchronous work transport system provides rigid pacing
- Undesirable aspects of rigid pacing:
  - Incompatible with inherent human variability
  - Emotionally and physically stressful to worker
  - Incomplete work units if task not completed
Pacing with Margin

- Worker is allowed to complete the task within a specified time range, the upper limit of which is greater than the cycle time.
- On average, the worker’s average task time must balance with the cycle time of the line.
- How to achieve pacing with margin:
  - Allow queues of work units between stations (asynchronous transport)
  - Provide for tolerance time to be longer than cycle time (continuous transport)
  - Allow worker to move beyond station boundaries
No Pacing

- No time limit within which task must be completed
- Each assembly worker works at his/her own pace
- No pacing can occur when:
  - Manual transport of work units is used on the line
  - Work units can be removed from the conveyor to perform the task
  - An asynchronous conveyor is used and the worker controls the release of each work unit from the station

There is no mechanical means of achieving a pacing discipline on the line.
Coping with Product Variety

- Single model assembly line (SMAL)
  - Every work unit is the same (products with high demand)
- Batch model assembly line (BMAL)
  - Hard product variety
  - Products must be made in batches
- Mixed model assembly line (MMAL)
  - Soft product variety
  - Models can be assembled simultaneously without batching on the line
MMAL vs. BMAL

- Advantages of mixed model lines over batch models lines:
  - No lost production time changing over between models.
  - High inventories typical of batch production are avoided.
  - Production rates of different models can be adjusted as product demand changes.
MMAL vs. BMAL

- Difficulties with mixed model line compared to batch model line
  - Line balancing problem is more complex due to differences in work elements among models.
  - Scheduling the sequence of the different models is a problem
  - Logistics is a problem - getting the right parts to each workstation for the model currently there.
  - Cannot accommodate as wide model variations as BMAL.
Line Balancing Problem

Given:
- Total work content consists of many distinct work elements
- The sequence in which the elements can be performed is restricted
- The line must operate at a specified cycle time

Problem:
- To assign the individual work elements to workstations so that all workers have an equal amount of work to perform
Components of cycle time at several workstations on a manual assembly line. At the bottleneck station, there is no idle time.
Precedence Constraints

- Restrictions on the order in which work elements can be performed

Precedence diagram
Line Balancing Algorithms

- Largest Candidate Rule
  - Assignment of work elements to stations based on amount of time each work element requires

- Kilbridge and Wester Method
  - Assignment of work elements to stations based on position in the precedence diagram
  - Elements at front of diagram are assigned first

- Ranked Positional Weights
  - Combines the two preceding approaches by calculating an RPW for each element
Mixed Model Assembly Lines

“A manual production line capable of producing a variety of different product models simultaneously and continuously (not in batches)”

- Problems in designing and operating a MMAL:
  - Determining number of workers on the line
  - Line balancing - same basic problem as in SMAL except differences in work elements among models must be considered
  - Model launching - determining the sequence in which different models will be launched onto the line
Other Considerations in Line Design

- Line efficiency
  - Management is responsible to maintain line operation at efficiencies (proportion uptime) close to 100%
    - Implement preventive maintenance
    - Well-trained emergency repair crews to quickly fix breakdowns when they occur
    - Avoid shortages of incoming parts to avoid forced downtime
    - Insist on highest quality components from suppliers to avoid downtime due to poor quality parts
Other Considerations - continued

- Methods analysis
  - To analyze methods at bottleneck or other troublesome workstations
- Subdividing work elements
  - It may be technically possible to subdivide some work elements to achieve a better line balance
- Sharing work elements between two adjacent stations
  - Alternative cycles between two workers
Other Considerations - continued

- Utility workers
  - To relieve congestion at stations that are temporarily overloaded
- Changing workhead speeds at mechanized stations
  - Increase power feed or speed to achieve a better line balance
- Preassembly of components
  - Prepare certain subassemblies off-line to reduce work content time on the final assembly line
Other Considerations - continued

- Storage buffers between stations
  - To permit continued operation of certain sections of the line when other sections break down
  - To smooth production between stations with large task time variations
- Parallel stations
  - To reduce time at bottleneck stations that have unusually long task times
Other Considerations - continued

- Zoning constraints - limitations on the grouping of work elements and/or their allocation to workstations
  - Positive zoning constraints
    - Work elements should be grouped at same station
    - Example: spray painting elements
  - Negative zoning constraints
    - Elements that might interfere with each other
    - Separate delicate adjustments from loud noises
Other Considerations - continued

- Position constraints
  - Encountered in assembly of large products such as trucks and cars, making it difficult for one worker to perform tasks on both sides of the product
  - To address, assembly workers are positioned on both sides of the line
Alternative Assembly Systems

- Single-station manual assembly cell
- Worker teams
- Automated assembly systems
Single-Station Manual Cell

“A single workstation in which all of the assembly work is accomplished on the product or on some major subassembly”

- Common for complex products produced in small quantities, sometimes one-of-a-kind
  - Custom-engineered products
  - Prototypes
  - Industrial equipment (e.g., machine tools)
Assembly by Worker Teams

“Multiple workers assigned to a common assembly task”

- Workers set their own pace
- Examples
  - Single-station cell with multiple workers
  - Swedish car assembly (job enlargement) - product is moved through multiple workstations by AGVS, but same worker team follows it from station to station
Reported Benefits of Team Assembly

- Greater worker satisfaction
- Better product quality
- Increased capability to cope with model variations
- Greater ability to cope with problems that require more time rather than stopping the entire production line
- Disadvantage:
  - Team assembly is not capable of the high production rates of a conventional assembly line